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Search for the solar neutrons using the Yangbajing neutron monitor and the neutron telescope during the 23rd solar cycle

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The geographical location of Yangbajing (latitude 30, 4300m above sea level) has advantages for the direct detection of the solar flare neutron events. The Yangbajing neutron monitor and neutron telescope were established in 1998 October at Yangbajing under the China-Japan cooperation and be used for the observation of solar neutron events during the 23th solar cycle. On 28 November 1998 the Yangbajing neutron monitor recorded a 3.8 sigma excess that has time coincidence with the reported neutron event of the Yangbajing neutron telescope. The response of Yangbajing neutron monitor and neutron telescope on the solar particle event associated with the X17.2 class flare at October 28, 2003 was researched too.

1. Introduction

The Yangbajing International Cosmic Ray Observatory is located at 30.11° N,90.53°E, 4300m above sea level, With mean atmospheric pressure 603 hPa and the cosmic ray vertical cut of rigidity 14.1GV. Its high altitude and low latitude has several advantages for the direct detection of the solar flare neutron events:

1. The high altitudes Neutron monitor have higher counting rates than at lower altitudes because of the atmospheric absorption of the cosmic ray secondaries generated near the top of the atmosphere.
2. The unambiguous determination of whether a NM count rate increase is due to solar neutrons is fraught with difficulties. To have at least one NM observing the increase at $P_c > 10GV$[1], is helped for the analysis of a solar neutron event.
3. At low-latitudes, the zenith from the subsolar point is small than at high-latitudes.

The Yangbajing 28 NM-64 neutron monitor record the single counts and multiplicities from one to eight for every two adjacent counters every second. The total counting rate in average were 1.07$\times$10^7 counts/hour[2].

The Yangbajing neutron telescope consists of 9m^2 scintillation counters and proportional counters which can determine (9$\times$9) arrival direction of neutrons. The maximum energy of neutrons measured by this telescope is higher than 240MeV[3].

As reported before, in association with a X3.3 flare on November 28th 1998, the Yangbajing neutron telescope possibly observed an arrival of high energy solar neutrons with the statistical significance of $\sim 4\sigma$ [4] and at same observatory in Tibet, the Yangbajing neutron monitor shows the 3-minute excess about 1.7 σ[2].

The period from October to November 2003 turned out to be the richest in the number and strength of events detected by ground-based neutron monitors in the 23rd cycle of solar activity. Neutron monitors have detected on October 28 and 29, and on November 2 three ground level enhancements (GLEs) of solar CRs. All three enhancements have common features. They were a result of sporadic phenomena in one and the same active region 10486 and were observed after extremely strong X-ray flares(X17.2/4B,X10.0/2B,and X8.3/2B). During the period of 11:10 to 11:15 UT, a small impulsive enhancement were probably detected by the neutron monitor Tsumeb in South Africa(S19.2°,E17.58°, 1240m above sea level, $R_c = 9.21GV$). It can be associated with solar neutrons. At that time, according to Moscow station's records, RSPs(relativistic solar particles) did not yet arrive at the Earth(the profile of Moscow station, 2.4GV), while according to the data of $CORONAS-F$ the gamma ray emission(an indicator of generation of neutrons) was observed from 11:04 to 11;12 UT[5].

According to the count rates measured by selected stations of the $SpaceshipEarth$ neutron monitor network as a function of time on 28 October 2003, the time profile of these count rates display several unusual features. First, a few stations observed a large, narrow spike at event onset. Second, the earliest arriving particles were detected by stations observing the anti-Sunward hemisphere. Third, the event displayed an unusually slow decay. Fourth, the near-equatorial neutron monitor in Tsumeb, Namibia observed a small but clear increase in count rate beginning at 11:06 UT and lasting for $\sim$9 minutes [6].

At Yangbajing, the observation of the neutron monitor and the neutron telescope at same location will get plentiful information about relativistic solar cosmic rays. In this paper, We present an overview of the neutron monitor and the neutron telescope which concern the 1998 November 28th event and the 2003 October 28th event.

2. 1998 November 28th event

We reanalyzed the data of the Yangbajing neutron telescope and the neutron monitor on 1998 November 28.

Figure 1 shows three-minute count rate from the south direction observed by the Yangbajing neutron telescope on 1998 November 28. The background level is obtained using a fitting of a binomial$(ax^2 + bx + c)$ to $\pm$30 minute data. A 4.9σ excess can be seen at 13:38:20-13:41:20 of the local time (Beijing Time) or 5:38:20-5:41:20(UT).

Figure 2 shows five-minute count rate of the Yangbajing neutron monitor on 1998 November 28. The background level is obtained by taking a running average for$\pm$30 minute. A 3.8σ excess can be seen at 5:38:00-5:43:00(UT).

3. 2003 October 28th event

The Figure 3 shows the observation of the Yangbajing neutron monitor on 2003 October 28. For five-minute count rate, a 6.4σ excess can be seen at 11:24:45-11:29:45(UT). For the one-minute count rate, a 3.8σ excess at 11:03:12-11:04:12(UT) and a 4.9σ excess at 11:24:12-11:25:12(UT) can be seen respectively.

The Figure 4 shows the observation of the Yangbajing neutron telescope on 2003 October 28. For One-minute count rate from the î west regionî (Fig5a), a 7.5σ excess can be seen at 11:06:36-11:07:36(UT). For two-minute count rate from the î west regionî (Fig5b), a 4.8σ excess at 11:00:12-11:01:12(UT) and a 8.9σ excess at 11:24:12-11:26:12(UT) can be seen respectively.

note that, considered the real significance distribution is not a normal gaussion, all the excesses mentioned above will be reduced by factor $\sim$ 1.4.

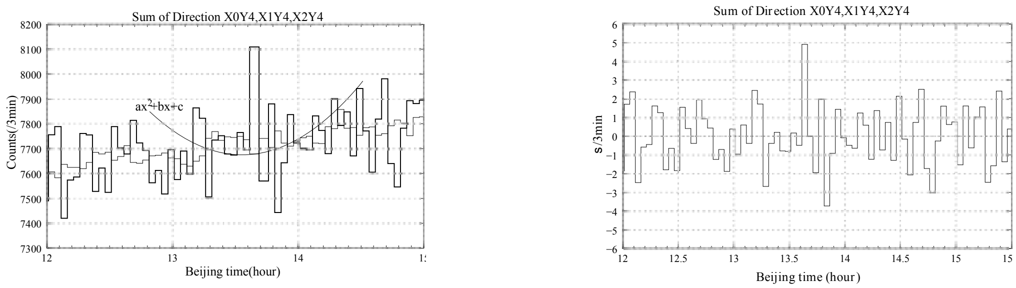

Figure 1. Three-minute count rate from the south direction(X0Y4,X1Y4,X2Y4) observed by the Yangbajing neutron telescope on 1998 November 28. The left panel is the time profile of observed by the neutron monitor and background. The dashed line is the averaged background. The right panel is the statistical significance. A 4.9σ excess can be seen at 13:38:20-13:41:20 of the local time (Beijing Time) or 5:38:20-5:41:20(UT).

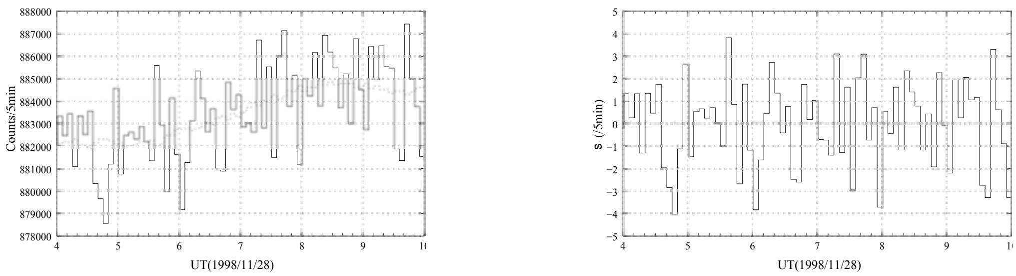

Figure 2. Five-minute count rate observed by the Yangbajing neutron monitor on 1998 November 28. All data are the pressure-corrected. The left panel is the time profile observed by the neutron monitor and background. The dashed line is the averaged background. The right panel is the statistical significance. A 3.8σ excess can be seen at 5:38:00-5:43:00(UT).

4. Conclusions

Associated with the X3.3 class flare on 28 November 1998 the Yangbajing neutron monitor recorded a 3.8 σ excess that has time coincidence with a 4.9 σ excess of the Yangbajing neutron telescope. This event confirmed that the neutron telescope is more sensitive to detect neutron than the neutron monitor.

Associated with the X17.2 class flare on 28 October 2003,the Yangbajing neutron monitor and neutron telescope observed several narrow spike simultaneously. It is clear that its 6.4σ excess for five-minute at 11:24:45-11:29:45(UT) for the neutron monitor and the 8.9σ excess for two-minute count rate at 11:24:12-11:26:12(UT) from îwest regionî are resulted from solar protons. And it is likely that the 3.8σ excess for one-minute count rate at 11:03:12-11:04:12(UT) for the neutron monitor and the 7.5σ excess for one-minute count rate at 11:06:36-11:07:36(UT) are resulted from neutron. The difference of the signal excess time could be explained by the energy of the solar neutron. It is coincidence with the results of Tsumeb neutron monitor with a small but clear increase beginning at 11:06 UT.

For the flare on 28 November 1998 and on 28 October 2003,the sun was observed at the zenith angle of about 50 degrees and 90 degrees at Yangbajing respectively. These events provide new evidences of the neutron deflected effect in the atmosphere.

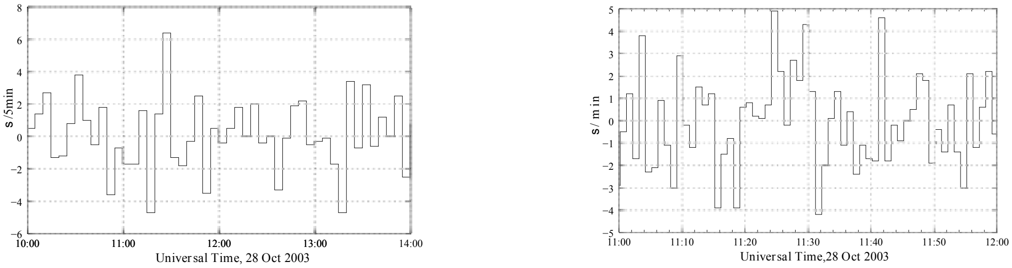

Figure 3. The observation of the Yangbajing neutron monitor on 2003 October 28. All data are the pressure-corrected. The left panel is the statistical significance of the five-minute count rate. A 6.4σ excess can be seen at 11:24:45-11:29:45(UT). The right panel is the statistical significance of the one-minute count rate. A 3.8σ excess at 11:03:12-11:04:12(UT) and a 4.9σ excess at 11:24:12-11:25:12(UT) can be seen respectively.

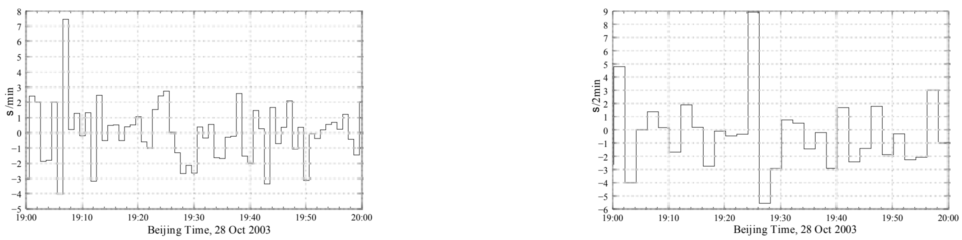

Figure 4. The observation of the Yangbajing neutron telescope on 2003 October 28. The left panel is the statistical significance of one-minute count rate from the west direction (Fig5 a). A 7.5σ excess can be seen at 19:06:36-19:07:36 of the local time (Beijing Time) or 11:06:36-11:07:36(UT). The right panel is the statistical significance of two-minute count rate from the west direction (Fig5 b). A 4.8σ excess at 19:00:12-19:01:12 of the local time (Beijing Time) or 11:00:12-11:01:12(UT) and a 8.9σ excess at 19:24:12-19:6:12 of the local time (Beijing Time) or 11:24:12-11:26:12(UT) can be seen respectively.

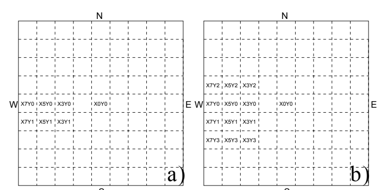

Figure 5. The west directs the neutron telescope. The left panel shows the 6 directs (X7Y0, X5Y0, X3Y0, X7Y1, X5Y1). The right panel shows the 12 directs (X7Y2, X5Y2, X3Y2, X7Y0, X5Y0, X3Y0, X7Y1, X5Y1, X7Y3, X5Y3, X3Y3).

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